IRON DEFICIENCY CHLOROSIS IN SORGHUM

by

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TABLE OF CONTENTS

LIST OF TABLES

Page

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" And dreaming, as it were, held brotherly speech
With one whose thought I had not hoped to reach

'Men work together,' I told him from the heart,
'Whether they work together or apart.'"

- Robert Frost -

C. Roger Bowen

I. THE INHERITANCE OF IRON EFFICIENCY AND THE EFFECT OF CHLOROSIS ON BIOMASS IN GRAIN SORGHUM.

ABSTRACT

The purpose of these investigations was to evaluate the effect of iron deficiency chlorosis on biomass and to investigate the inheritance of iron efficiency in sorghum (Sorghum bicolor (L.) Moench) grown in a soil near Garden City, Kansas known to cause iron deficiency chlorosis. Random S_1 derived lines from KMPlFe, a population having undergone recurrent phenotypic selection for iron efficiency were classified into three groups of short (75-118 cm), medium (119-141 cm) and tall (142-175 cm) entries. Single row plots were visually evaluated for chlorosis 46 days after planting in 1983 and 32 and 48 days after planting in 1984. Chlorosis scores for the two years were significantly correlated (r=0.82). Biomass was measured from three meter lengths of competitive row length harvested 75 days after planting, prior to grain fill in 1984. Chlorosis scores in 1983, the mean of 1984 scores and the mean of both years were all negatively correlated with biomass. Regression analysis indicated that chlorosis had a major effect on biomass.

Parents and progeny of a factoral mating design involving four females and twenty-five males were planted in a four rep blocks in replications (BIR) design at the same site in 1984. Plots were evaluated for chlorosis 48 and 74 days after planting. The inheritance of chlorosis score was largely additive; general combining ability accounted for 80% of the genetic variance among hybrids and mid-parent heterosis was only 5%. Male line performance per se and inter se were significantly correlated.

INTRODUCTION

The Great Plains region is responsible for approximately 75 percent of grain sorghum (Sorghum bicolor (L.) Moench) production in the United States (USDA Agricultural Statistics, 1983). The calcareous nature and other properties of many Great Plains soils can cause the unavailability of iron and subsequent deficiency chlorosis in sorghum. Regreening of plant tissue and/or an increase in yield has occured in field grown chlorotic sorghum plants treated with various forms of iron or iron chelating residues (Hagstrom, 1984; Matocha, 1984). A negative relationship between iron chlorosis and seedling dry weight has been seen in hydroponically grown sorghum plants (Mikesell et al., 1973; Williams et al., 1982). Froehlich and Fehr (1981) showed a negative relationship between iron deficiency chlorosis and seed yield in soybeans (Glycine max (L.) Merrill). Although Gerbermann and Gausman (1977) have shown grain yields to be lower in more chlorotic sections of affected fields using infra-red photography there are no published conventional field experiments that have quantified the effect of iron chlorosis on biomass. Such information could help assess the severity of the problem and define the requirements of a solution.

Many researchers agree that a genetic cure is the most practical alternative to solving the iron chlorosis problem in grain sorghum (Clark, 1982; Wallace, 1982; Fehr, 1984). Advances to this end depend on identifying iron efficient lines and on understanding the mode of inheritance in order to

transfer this characteristic into commercially acceptable lines. This has been accomplished in soybeans (Cianzio and Fehr, 1980; Fehr and Cianzio,1980; Fehr 1982). Unfortunately studies concerning the inheritance of iron efficiency in sorghum have either been inconclusive or contradictory (Mikesell et al, 1973; Mushi and Langston,1975; Esty et al, 1980).

The objectives of this study were to evaluate the relationship between of iron deficiency chlorosis and biomass and to investigate the inheritance of iron efficiency in sorghum grown on soil known to induce iron deficiency chlorosis.

MATERIALS AND METHODS

Experiments were conducted at the Kansas State University Branch Experiment Station at Garden City, Kansas in 1983 and 1984 on a Ulysses Silt Loam soil that previously had approximately one meter of topsoil removed for terracing. Noteable properties of the soil were its high pH (8.1) and Ca level (4900 ppm), low organic matter (1.3%) and relatively low amount of DTPA extractable iron (4.5 ppm). The soil was considered "severe" in causing chlorosis in sorghum. Levels of N, P and K were 11 ppm, 621 ppm and 11 ppm,respectively, prior to fertilization. The field was fertilized with 201.6 kg ha^{-1} N in the form of NH_4. Propachlor was applied as a post planting /preemergence herbicide at the rate of 3.4 kg ha^{-1}.

Line Evaluation

Progeny of selfed lines from KMPlFe, a random mating sorghum population that had previously undergone recurrent phenotypic selection for iron efficiency (A. J. Casady, USDA-retired, personal communication) were classed by height into three groups: short (75 - 118 cm), medium (119 - 141 cm) and tall (142 - 175 cm). Eighteen lines were selected at random to represent each height class.

In 1983 these 54 lines were planted July 3 in a 5 rep randomized complete block experiment. Short check varieties included in the study were two entries of Dwarf Redlan, a close relative of the iron inefficient line Redlan (Williams et al., 1982; McKenzie et al., 1984), and KS 5, an iron efficient line

(Mikesell et al., 1973). Plots consisted of single rows, 1.02m wide and 4.5m long. Plant density was aproximately 110,000 plants per hectare. Plots in 1983 were rated for iron deficiency chlorosis 46 days after planting. Scores were based on a modified scale of a system in common use (Cianzio et al., 1979; Clark et al., 1982; Coulombe et al., 1984; Loeppert et al., 1984; McKenzie et al., 1984; Williams et al., 1982). Plants showing no chlorosis were rated 0. A score of 1 was given to plants with slight yellowing. Plants with chlorotic interveinal tissue and with green and yellow veins recieved scores of 3 and 4, respectively. Totally chlorotic plants with associated necrosis were rated 5. Because of the severity of the conditions a score of 6 was added to denote plots with plants that had died as a result of chlorosis.

Bulked selfed seed from KMPlFe lines planted in 1983 were planted June 8,1984. In addition to genotypes used in the 1983 study the 1984 study included Plainsman and two-dwarf Plainsman as efficient checks (Williams et al, 1982) and Redlan and two-dwarf Redlan as inefficient checks. Susceptible checks were each entered twice. The study employed a 6 rep incomplete block design, blocks in replications (BIR) (Schutz and Cockerham, 1962) with 7 entries per block. Single plots of the same dimensions as the 1983 test were overplanted and thinned to approximately 65,500 plants per hectare. Plots were visualy evaluated for chlorosis 32 and 48 days after planting. The data used for 1984 was the mean of the two dates. Analysis of variance was calculated for visual iron deficiency chlorosis

scores for entries common to both 1983 and 1984 (Table 1). Because the number of replications differed between the two years, the combined data set was unbalanced. Plot error was estimated by the the pooled plot error mean squares from each of the two years. Other mean squares were calculated by weighting data from each year equally after calculating means over reps, and then scaling the mean squares upward using the harmonic mean of rep number as a coefficient. Biomass was measured by harvesting all above ground plant material prior to grain fill, 75 days after planting in three meter competitive row lengths. Dry weights were determined by drying a representative sample at 60^{o}C in a forced-air oven. An analysis of variance for the biomass data is presented in Table 2.

Plant height and maturity data were obtained in 1984 at the Kansas State University North Agronomy Farm, Manhattan, Kansas, a non-chlorotic environment. Phenotypic correlation coefficients were computed on entry means for chlorosis scores for each year, the mean of chlorosis scores over years, biomass, yield in 1984, plant height and maturity.

Mating Design

Twenty-five diverse lines were crossed as males with 4 female (A) lines to produce 100 F1 hybrids. The male group included ten S_2 selections from KMPlFe in addition to a diverse set of R and B lines. In 1984 a 4 rep experiment was conducted using these 29 parental lines and 100 F1 hybrids in a BIR design. Blocks were composed of 13 random entries. Plots consisted of single 4.5m rows spaced 1.02m apart with a

population of aproximately 110,000 plants per acre.

Plots were scored for chlorosis 48 and 74 days after planting. An analysis of variance was performed on the mean of these two scores (Table 7). General and specific combining ability variances were estimated by partitioning the variability due to hybrid effects into male effects, female effects and the interaction between male and female parents. Variance components for each of these effects were derived from expected mean squares (Table 7).

RESULTS

Line Evaluation

The combined years analysis of variance for chlorosis showed significant differences among and within all height groups except for the comparison between the short and medium groups (Table 1). The coresponding entry by year interaction mean square was used to test for entry effects. The chlorosis mean square for entry by year interaction was significant. In 1984 all comparisons involving biomass in all height classes were significant (Table 2). Entry means for chlorosis scores in 1983, 1984, mean chlorosis score for both years and biomass entry means are presented for each of the height groups, respectively, in Tables 3, 4, and 5.

The iron inefficient check varieties ranked last for chlorosis score in 1983 and 1984 within their respective height classes. These entries also ranked last for biomass in all height groups. Iron efficient checks, Plainsman and Plainsman two-dwarf, generally yielded less biomass and were more chlorotic than most of the lines from KMPlFe, whereas KS 5 was generally intermediate for both traits.

The mean chlorosis score of the tall group was significantly less than the short and medium groups in both years. Also, the mean biomass of the tall group was significantly larger than that of the other two groups. Chlorosis ratings were generally higher in 1984 with the greatest difference between the two years being among the more

iron efficient entries.

Correlation coefficients were computed to show the linear relationships among entry means for chlorosis score in 1983 and 1984, mean chlorosis score over years, biomass, maturity and height (Table 6). There was a strong linear relationship between 1983 and 1984 chlorosis scores (Figure I-1). All other associations were significant except for those involving maturity. Maturity was significantly negatively correlated with 1984 chlorosis score but with no other trait. A non-significant trend was the positive correlation between biomass and maturity. Biomass was negatively associated with chlorosis scores in each year and the mean of both years. Height was negatively correlated with chlorosis and positively correlated with biomass. Correlation coefficients were larger in magnitude for biomass with chlorosis than for biomass with height.

Chlorosis seemed to have a causal relationship on the amount of biomass. Polynomial regression analysis was performed to explain the variability in biomass with chlorosis scores. Only linear and quadratic models were significant. Thus the following model was used:

$$\text{BIOMASS} = 347.6 + 38.2\ C - 31.2\ C^2$$

The value of C is defined as the entry mean for chlorosis for the combined years. The proportion of variability in biomass explained by the model, R^2, was 0.73 (Figure I-3). A similar model using 1984 chlorosis scores to explain biomass yielded an R^2 value of 0.86 (Figure I-2). Other models were constructed using height and maturity data but neither was significant when chlorosis score was included in the model.

Mating Design

The effects of parents, hybrids, and parents versus hybrids for mean chlorosis score of the two years were significant (Table 7). Male parents, female parents, and the difference between the two were also significant. Mean chlorosis scores of F_1 hybrids, lines and mean performance of lines in F_1 combination (inter se) are presented in Table 8. Selections from KMPlFe performed well relative to other males. Among females, Dwarf Redlan and Wheatland had the highest chlorosis scores and their hybrids tended to be more chlorotic than hybrids of KS 5 and KS 45.

The mean chlorosis score of all hybrids was 2.90 and the weighted mean of parents was 3.04. Mid-parent heterosis, the mean of hybrids minus the mean of their parents divided by the mean of the parents was -0.05. This indicates only a slight decrease in chlorosis for the hybrids than what would be expected of a completely additively inherited trait.

The hybrid class was partitioned into male, female, and male by female interaction terms. All of their corresponding mean squares were significant. The sum of the male and female components of variance was used to estimate general combining ability variance. Specific combining ability variance was estimated from the male by female interaction components (Table 7). The percent variance due to specific combining ability was smaller than that due to either the male or female component of variance. General combining ability accounted for 80.46 percent of the total genetic variance.

Correlation coefficients among males in hybrid combination with each female, male lines per se and mean male line performance over all females (males inter se) are shown in Table 9. Strong linear associations were noted in all cases among male lines inter se except for the performance of males combined with Ks 45. Also, the performance of hybrids with Ks 45 as a parent showed less of a linear relationship with the scores of male lines per se.

DISCUSSION

This study was designed to determine the effect of iron deficiency chlorosis on biomass and to investigate the inheritance of iron efficiency on a field soil known to be severely affected by iron deficiency chlorosis. It has been shown that a genotype's relative chlorosiss response can differ with locations in lovegrass (*Eragrostis curvula* (Schrad.) Nees) (Voight et al 1982) and in sorghum (Loeppert et al, 1984). Chlorosis ratings for lines in these experiments were relatively the same as the same lines in other experiments at different locations. (Mikesell et el., 1973; Williams et al., 1982; McKenzie et al., 1984).

Selections from KMPlFe generally yielded more biomass and displayed less chlorosis than the check varieties. The mean chlorosis scores of the tall group in 1983, 1984 and their mean score over both years were significantly lower than those for the short and medium groups. Biomass was significantly greater for the tall than the other height groups. Also, the shorter and later maturing entries were more chlorotic and produced less biomass than earlier, taller entries. These difference could be attributed to linkage, pleiotropy or non-random mating due to maturity. Many of the original lines forming KMPlFe were tall and selection pressure over cycles was primarily for iron efficiency. Although biomass was significantly negatively correlated with plant height it is important to note that many shorter iron efficient entries produced more biomass than less

efficient tall entries. Also, the short entries from KMP1Fe are substantially more iron efficient than most of the current commercially important inbreds. The relatively poor performance of the widely used inbreds Wheatland and Redlan suggests that genetic improvement is necessary if they are to be grown in affected soils.

Chlorosis scores were higher in 1984 than 1983 with the greatest difference being between the most iron efficient entries. This is recognized by comparing the means of the short and the more efficient tall classes in both years. The difference between years may be due to the late planting date in 1983. These differences may also be attributable to the subjective nature of a visual rating system (Cianzio et al., 1981; McKenzie et al., 1984). Subjective differences between years in the relative rating of entries would inflate the entry by year mean square for chlorosis. Despite these differences chlorosis scores in 1983, 1984 and the mean of the two years were highly correlated.

Froehlich et al. (1981) observed a relationship between seed yield and chlorosis score in soybeans. Williams et al.(1982) noted a similar relationship between sorghum seedling dry weight and chlorosis in extreme genotypes grown hydroponically in the greenhouse. In this study a strong negative relationship existed between chlorosis score and biomass. Although height was positively correlated with biomass, this relationship was less significant than the relationship between chlorosis score and biomass. The combined evidence from regression and correlation analysis supports the

concept that biomass is affected by iron deficiency and subsequent chlorosis in environments low in available iron. Possibly, in this study, the severity of chlorosis, as indicated by the occurrence of highly necrotic plants accentuated this relationship.

Unlike soybeans (Cianzio and Fehr, 1980), no simple pattern of iron efficiency inheritance has been reported in sorghum. Mikesell et al. (1973) suggested in a greenhouse study that iron efficiency in sorghum was not simply inherited. Similarly, Mushi et al. (1975) concluded a a complex system of inheritance of iron efficiency in sorghum plants grown in soil in greenhouse experiments. Esty et al. (1980) studying seedlings grown in nutrient solutions suggested that dominance or overdominace was involved in the genetics of transmission of iron efficiency in sorghum. Evidence provided by the mating design study supports inheritance being primarilly additive. General combining ability had a major influence on chlorosis accounting for approximately 80% of the hybrid genetic variance. A strong correlation existed between the chlorosis scores of male lines per se and male topcross (inter se) means (Table 9). This suggests that the performance of a line per se is a good predictor of its performance in hybrid combination. Also, the level of heterosis was only 5%. Probably the genes affecting chlorosis are primarily additive with dominant effects being of lesser importance. It was impossible to estimate epistatic effects in this study but they were presumably small. Epistatic variance is a component of specific combining ability which was

relatively small.

Despite overwhelming evidence for additive genetic control of iron chlorosis the importance of specific parental combininations was indicated by the significant F ratio for male by female interaction. A specific example of non-additive gene action is apparent when comparing the line per se and inter se values for KMP1Fe-58. The average hybrid chlorosis score was above the score expected if the trait was additively transmitted thus indicating some dominant gene action for iron inefficiency. In contrast, KMP1Fe-14 and KMP1Fe-108, lines with the same chlorosis score as KMP1Fe-58, produced hybrids that were statistically indistiguishable from each other, based on either their predicted or actual hybrid performance. These hybrids were significantly less chlorotic than those of KMP1Fe-58. An opposite trend was noted with Tx 2536. This supports the work of Esty et al. (1980) who reported heterotic or dominance effects for iron efficiency in F_1 crosses with Tx 2536.

Hybrid performance of males with specific females generally correlated well with the performance of the corresponding male lines per se and inter se (Table 9). However, there was less of a linear relationship of hybrids of KS 45 than with the other females suggesting it to be genetically divergent in terms of iron efficiency from the other females.

The strong negative correlation between biomass and chlorosis score in this study indicates that iron deficiency chlorosis could be a major limiting factor of sorghum yields in severely affected areas. Results from this study combined with others suggest a large potential for genetic improvement of

sorghum in regard to iron deficiency chlorosis and subsequently yield. Iron chlorosis is seemingly a complex trait controlled by at least several, predominately additive, genes. Recurrent selection has been shown to be a successful technique for improving iron efficiency in soybeans (Prohaska and Fehr, 1981). The improved performance of selections from KMP1FE is an indication of the effectiveness of reccurent phenotypic selection for the improvement of sorghum for iron efficiency. The apparent additive inheritance of iron efficiency indicates potential parental lines of commercial hybrids could be selected per se without costly testcross analysis.

Table I-1. Analysis of variance of iron deficiency chlorosis scores for random lines from KMP1Fe sorghum population and check lines evaluated in 1983 and 1984 at Garden City, KS.

Source	df	Mean Square
Year	1	3.099**
Rep	4.45	3.565**
Entry	56	4.768**
Among height classes	2	41.322*
Tall vs 1/2(Short + Medium)	1	80.621**
Short vs Medium	1	1.978
Within height classes	54	3.414**
Short	20	4.108**
Medium	17	2.237**
Tall	17	3.775**
Entry x year	56	0.533*
Among height classes x year	2	0.197
Tall vs 1/2(Short + Medium) x year	1	0.099
Short vs Medium x year	1	0.249
Within height classes x year	54	0.546*
Short x year	20	0.506*
Medium x year	17	0.525*
Tall x year	17	0.614*
Plot error	498.9	0.314

*,** Significant at $p \leq 0.05$ and 0.01, respectively.

Table I-2. Analysis of variance of biomass for random lines from KMP1Fe sorghum population grouped into classes of similar heights and check lines evaluated at Garden City, KS in 1984.

Source	df	Mean Square
Rep	5	121 096**
Entry	62	57 419**
Among height classes	2	144 072**
Tall vs 1/2(short + medium)	1	263 076**
Short vs medium	1	25 067**
Within Height classes	60	54 531**
Short	20	55 389**
Medium	20	51 332**
Tall	20	56 871**
Plot error	310	4 594

*,** Significant at $p \leq 0.05$ and 0.01, respectively.

Table I-3. Entry means and ranks of short (75-118 cm) random lines from KMPlFe evaluated at Garden City, Ks in 1983 and 1984 for iron deficiency chlorosis score and in 1984 for biomass.

	Visual evaluation						Biomass	
	1983		1984		Mean		1984	
Entry	Score	Rank	Score	Rank	Score	Rank	gm^{-2}	Rank
KMPlFe-37	1.60	1	1.87	1	1.73	1	351.02	3
KMPlFe-209	1.60	1	2.03	4	1.82	2	293.36	6
KMPlFe-136	2.00	5	1.87	1	1.93	3	384.77	1
KMPlFe-222	1.93	3	2.20	5	2.07	4	379.10	2
KS5	2.00	5	2.41	8	2.20	5	245.27	11
KMPlFe-19	1.95	4	2.53	10	2.24	6	233.70	16
KMPlFe-168	2.20	9	2.33	6	2.26	7	287.90	7
KMPlFe-174	2.00	5	2.58	12	2.29	8	221.38	14
KMPlFe-154	2.00	5	2.66	16	2.33	9	223.98	13
KMPlFe-254	2.40	11	2.36	7	2.38	10	269.47	9
KMPlFe-160	2.40	11	2.53	10	2.46	11	211.31	15
KMPlFe-13	2.20	9	2.74	17	2.47	12	249.25	10
KMPlFe-65	3.05	17	1.91	3	2.48	13	305.66	4
KMPlFe-133	2.60	13	2.41	8	2.50	14	294.70	5
KMPlFe-162	2.60	13	2.58	12	2.59	15	240.09	12
KMPlFe-135	2.80	15	2.83	14	2.81	16	175.78	17
KMPlFe-172	2.80	15	2.99	18	2.90	17	168.45	18
KMPlFe-178	3.20	18	2.62	15	2.91	18	278.07	8
KMPlFe-27	3.60	19	3.37	19	3.48	19	104.32	19
Dwf Redlan	3.79	20	4.16	20	3.98	20	45.95	20
Dwf Redlan	-	-	4.24	21	-	-	15.22	21
Mean	2.44		2.63		2.49		237.08	
LSD(0.05)	0.89		0.44		0.60		76.70	

Table I-4. Entry means and ranks of medium (119-142 cm) random lines from KMPlFe evaluated at Garden City, Ks in 1983 and 1984 for iron deficiency chlorosis score and in 1984 for biomass.

	Visual evaluation						Biomass	
	1983		1984		Mean		1984	
Entry	Score	Rank	Score	Rank	Score	Rank	gm^{-2}	Rank
KMPlFe-126	1.40	1	1.83	1	1.61	1	338.38	3
KMPlFe-75	1.40	1	1.91	3	1.65	2	341.31	2
KMPlFe-152	1.80	4	1.86	2	1.83	3	357.93	1
KMPlFe-125	2.00	5	2.28	7	2.14	4	239.50	11
KMPlFe- 41	1.54	3	2.87	14	2.20	5	183.81	14
KMPlFe-83	2.20	6	2.24	6	2.22	6	261.43	8
KMPlFe-73	2.40	8	2.12	4	2.26	7	298.24	4
KMPlFe-155	2.20	6	2.53	10	2.37	8	258.30	9
KMPlFe-77	2.60	11	2.20	5	2.40	9	268.85	7
KMPlFe-278	2.60	11	2.40	8	2.50	10	277.16	6
KMPlFe-204	2.60	11	2.49	9	2.55	11	295.52	5
KMPlFe-206	2.40	8	2.74	12	2.57	12	207.14	12
KMPlFe-270	2.40	8	2.91	15	2.65	13	150.23	17
KMPlFe-25	2.80	15	2.58	11	2.69	14	204.77	13
KMPlFe-141	2.60	11	3.40	19	3.00	15	151.49	16
KMPlFe-79	3.00	17	3.03	17	3.01	16	132.54	18
KMPlFe-66	2.80	16	3.28	18	3.04	17	101.08	19
KMPlFe-192	3.20	18	2.99	16	3.10	18	159.30	15
Plainsman	-	-	2.78	13	-	-	251.87	10
Redlan	-	-	3.78	20	-	-	57.72	20
Redlan	-	-	4.08	21	-	-	28.32	21
Mean	2.33		2.68		2.43		217.14	
LSD(0.05)	0.89		0.44		0.61		76.70	

Table I-5. Entry means and ranks of tall (143-175 cm) random lines from KMPlFe evaluated at Garden City, Ks in 1983 and 1984 for iron deficiency chlorosis score and in 1984 for biomass.

	Visual evaluation						Biomass	
	1983		1984		Mean		1984	
Entry	Score	Rank	Score	Rank	Score	Rank	gm^{-2}	Rank
KMPlFe-3	0.60	1	1.12	2	0.86	1	330.00	8
KMPlFe-107	1.00	5	0.91	1	0.95	2	395.27	2
KMPlFe-92	0.80	2	1.12	2	0.96	3	348.37	6
KMPlFe-150	0.80	2	1.33	4	1.06	4	272.95	13
KMPlFe-50	0.80	2	1.62	9	1.21	5	378.15	4
KMPlFe-219	1.00	5	1.49	6	1.25	6	408.58	1
KMPlFe-157	1.00	5	1.70	10	1.35	7	294.38	10
KMPlFe-176	1.40	8	1.53	7	1.47	8	270.08	16
KMPlFe-62	2.00	10	1.74	11	1.87	9	354.53	5
KMPlFe-63	2.20	11	1.58	8	1.89	10	395.37	3
KMPlFe-243	2.40	14	1.45	5	1.93	11	320.17	9
KMPlFe-142	1.80	9	2.16	12	1.98	12	340.78	7
KMPlFe-101	2.40	14	2.20	13	2.30	13	276.24	11
KMPlFe-69	2.20	11	2.49	17	2.35	14	252.09	17
KMPlFe-26	2.21	13	2.53	18	2.37	15	274.19	12
KMPlFe-166	2.60	18	2.20	13	2.40	16	259.09	18
KMPlFe-179	2.50	16	2.36	15	2.43	17	270.36	15
KMPlFe-198	2.54	17	2.41	16	2.48	18	271.68	14
Plainsman+	-	-	2.83	19	-	-	188.99	19
Redlan +	-	-	3.78	20	-	-	53.27	20
Redlan +	-	-	4.08	21	-	-	26.03	21
Mean	1.63		2.08		1.77		283.07	
LSD(0.05)	0.89		0.44		0.66		76.70	

+ Two dwarf.

Table I-6. Phenotypic correlation coefficients among visual iron deficiency chlorosis score for 1983, 1984 and combined mean score of the two years, biomass, height and relative maturity.

Characters	1984 Chlorosis score	Mean score of years	1984 Biomass	Maturity	Height
1983 Chlorosis score	0.82**	0.96**	-0.68**	0.05	0.57**
1984Chlorosisscore		0.95**	-0.91**	0.28*	-0.40**
Mean score of years			-0.82**	0.05	-0.58**
Biomass				-0.24	0.31*
Maturity					0.09

*, ** Significant at p≤0.05 and 0.01 respectively.

Table I-7. Analysis of variance of visual score for iron defiency chlorosis for four female parents, twenty-five male parents and their F1 hybrids evaluated at Garden City, KS and the components of genetic variance.

Source	df	Mean Square	Variance Component
Rep	3	3.567**	
Lines	28	3.903**	
Male	24	3.343**	
Female	3	4.433**	
Male vs female	1	15.782**	
Lines vs hybrids	1	5.322**	
Hybrids	99	1.498**	
Male	24	3.427**	0.183 +0.119
Female	3	9.984**	0.095 +0.063
Male x female	72	0.500**	0.067 +0.209
Error	384	0.231	

** Significant at $p \leq 0.01$.

Table I-8. Mean iron deficiency chlorosis scores for F1 hybrids and their male and female parents, per se and inter se, evaluated at Garden City, KS in 1984.

	Females				Male Means	
Males	Dwarf Redlan	Wheat-land	Ks 5	Ks 45	inter se#	per se+
KMPlFe-23	1.83	1.89	2.02	1.71	1.86	0.96
KMPlFe-75	2.52	2.83	1.71	2.39	2.36	1.65
KMPlFe-14	2.52	2.65	2.39	2.21	2.44	1.83
KMPlFe-108	2.58	2.65	2.52	2.08	2.46	1.83
KMPlFe-82	2.83	2.52	2.52	2.21	2.50	1.33
TP15-65	2.96	2.58	2.83	2.02	2.59	2.08
KMPlFe-69	2.71	2.71	2.77	2.33	2.63	2.21
Tx 2536	2.96	2.39	2.65	2.65	2.60	2.58
KMPlFe-67	3.02	3.08	2.71	1.83	2.61	1.33
TP15-87	2.96	2.58	2.46	2.71	2.68	2.02
KMPlFe-99	3.02	3.58	2.02	2.15	2.69	2.65
KMPlFe-120	3.15	3.20	2.21	2.33	2.72	1.71
Ks 69	3.89	3.02	1.83	2.39	2.79	3.02
Ks 11	3.27	2.58	2.89	2.58	2.83	2.33
Sc 56	2.83	3.65	2.58	2.39	2.86	2.48
TP15-114	3.56	3.65	3.39	2.08	2.94	2.48
KMPlFe-58	3.33	3.15	3.02	2.74	3.06	1.83
Ks 18	3.27	3.27	3.21	2.52	3.07	3.08
Ks 70	3.58	3.46	2.71	3.52	3.32	3.58
Sc 372	3.83	3.33	3.71	2.58	3.36	4.08
TP15-105	3.33	3.77	3.02	3.46	3.39	2.89
TP15-5	3.77	3.83	3.21	3.12	3.48	2.58
Ks 53	3.96	4.15	2.89	3.27	3.57	3.82
Sc 118	4.21	4.08	3.08	3.33	3.68	3.96
Ks 71	4.33	4.21	3.15	3.33	3.75	4.33
Female mean inter se@	3.21	3.11	2.70	2.56	-	-
Female mean per se#	4.49	4.46	2.89	2.46	-	-

+,@,# LSD values of 0.13, 0.33 and 0.67 respectively.

Table I-9. Correlation coefficients of iron deficiency chlorosis scores among male in hybrid combination with specific females and with male lines per se and inter se.

	Males per se	Males inter se
Dwarf Redlan	0.84**	0.91**
Wheatland	0.74**	0.87**
Ks 45	0.53**	0.69**
Ks 5	0.74**	0.85**
Male lines per se		0.86**

*, ** Correlation coefficient was significantly different from zero at 0.05, and 0.01 levels of probability, respectively.

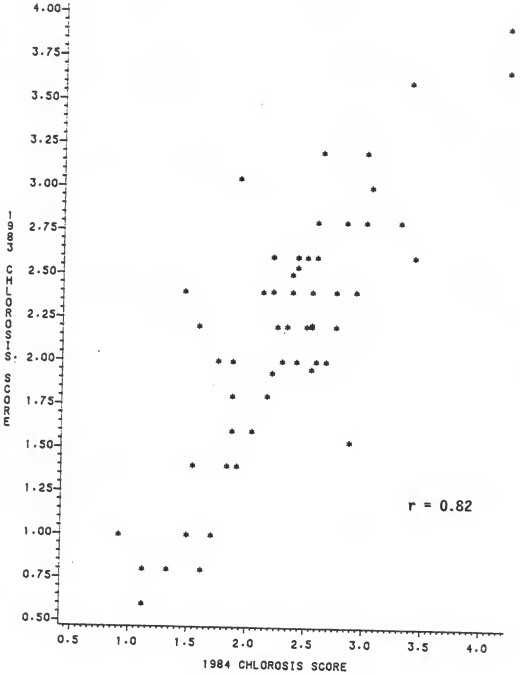

Figure I-1. The relationship of 1983 and 1984 chlorosis scores.

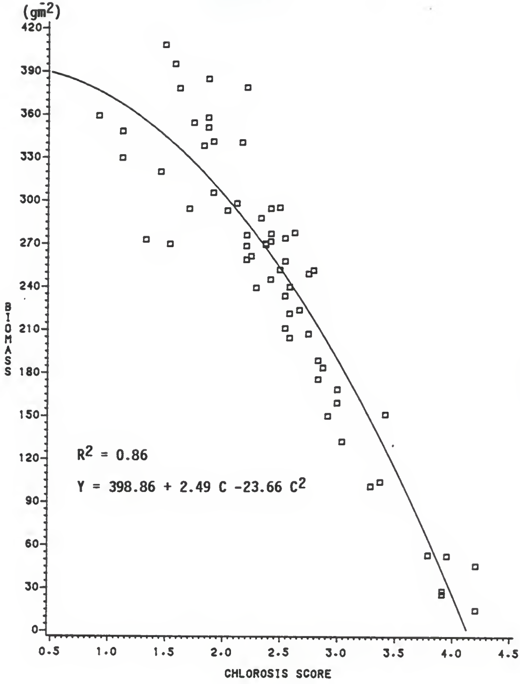

Figure I-2. The relationship of 1984 chlorosis score with 1984 biomass.

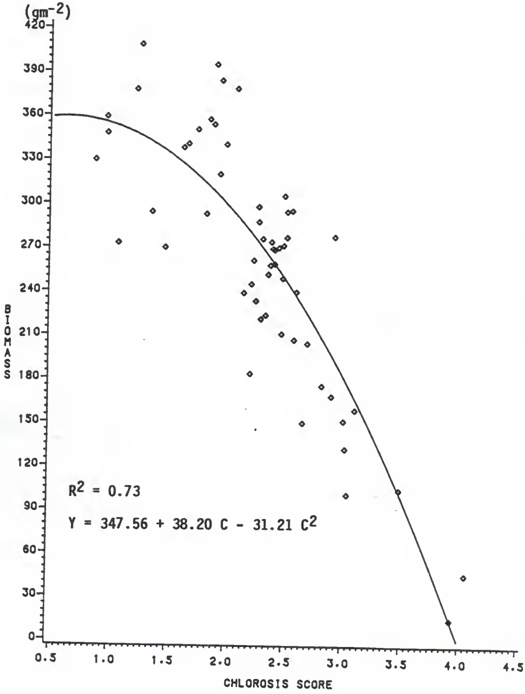

Figure I-3. The relationship of the mean of 1983 and 1984 chlorosis scores with 1984 biomass.

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II. EVALUATION OF A GREENHOUSE SCREENING TECHNIQUE.

ABSTRACT

The improvement of sorghum (*Sorghum bicolor* (L.) Moench) for iron deficiency chlorosis would be facilitated with the development of a greenhouse screening technique. The purpose of this research was to evaluate a greenhouse screening technique for predicting field iron deficiency chlorosis in sorghum. Seedlings were grown in a soil mixture high in pH and calcium , and low in organic matter and available iron. Three split plot experiments, all with six replications, were conducted in the greenhouse with FeEDDHA amended soil as a control treatment. Progeny of randomly selected lines from KMP1Fe, a population that has undergone recurrent phenotypic selection for iron efficiency, were divided into three height groups, short (75-118 cm), medium (119-141 cm) and tall (142-175 cm). Seedlings were evaluated for chlorosis, vigor, shoot length and dry weight. Mean squares for chlorosis were significant for the short and tall groups but not for the medium. Greenhouse results were compared to those of field experiment conducted on a site known to induce severe chlorosis symptoms in sorghum. Single row plots were visually evaluated for chlorosis 48 days after planting and biomass was determined for one meter lengths of competitive row 75 days after planting. Phenotypic correlations between greenhouse chlorosis scores for all entries grown in the soil mixture without FeEDDHA with field chlorosis scores and biomass were

significant. Regression analysis on the short non-chelated group using greenhouse chlorosis scores to describe field chlorosis and biomass provided R^2 values of 0.78 and 0.67, respectively. Results indicated that greenhouse chlorosis score could be used to predict field performance.

INTRODUCTION

Sorghum (<u>Sorghum bicolor</u> (L.) Moench) is climaticaly well suited to the Great Plains region of the United States. However, production is prohibited in certain soils of this area because of iron deficiency chlorosis (Clark, 1982a; Vose, 1982). These affected soils are typified as having high pH values, high calcium carbonate and low organic matter contents (Walace, 1982; Loeppert et al., 1984). Proposed corrections to this condition include foliar application of iron chelates or salts, amending the soils with iron compounds and/or acids and the incorporation of organic matter in the form of manures or crop residues (Wallace and Mueller, 1979; Matocha and Pennington, 1982; Anderson and Parkpian, 1984; Hagstrom, 1984; Matocha, 1984). Genotypes of sorghum vary in efficiency of iron utilization (Mikesell et al., 1973; Esty et al., 1980; McKenzie et al., 1984; Pierson et al., 1984). Clark et al. (1982b) and Fehr (1984) have suggested breeding iron efficient lines as a practical and permanent solution to iron deficiency chlorosis. Prohaska and Fehr (1981) have demonstrated improvements for iron-efficiency in soybeans (<u>Glycine max</u> (L.) Merrill).

The development of greenhouse screening techniques would reduce the time and expense required in field trials and thus increase the number of genotypes that could be evaluated. Coulombe et al. (1984) have demonstrated a non-field method of evaluating iron efficiency in soybean cultivars using nutrient solutions high in bicarbonate. Nutrient solution studies have demonstrated the variability in iron efficiency among sorghum

lines (Esty et al., 1980; Clark et al., 1982b; Williams et al., 1982). Although using nutrient solutions allows for precise control of the chemical composition of the root environment it does not simulate the chemical complexity of soil (Clark, 1982b; McKenzie et al., 1984; Uren,1984; Romheld and Marschner, 1984). Loeppert et al. (1984) demonstrated that soils from "hot spots", severely affected areas, used in greenhouse experiments with the iron-inefficient sorghum line Redlan produced seedlings with chlorotic responses similar to those seen in field grown seedlings.

The purpose of this study was to determine if iron efficiency and/or biomass of adult field sorghum plants in the field can be predicted by evaluating greenhouse seedlings grown in soil known to induce iron chlorosis. This study examines the usefulness of a soil based greenhouse screening method in evaluating sorghum lines derived from KMPFel, a population with improved iron efficiency, by comparing greenhouse and field results.

MATERIAL AND METHODS

Progeny of random, presumabley S_1 lines from KMPFel, a sorghum population improved for iron efficiency, (A. J. Casady, USDA-retired, personal communication) were classifieded into three height groups, short (75-118 cm), medium (119-141 cm) and tall (142-175 cm). Twenty-two lines were randomly chosen to represent each height group.

Greenhouse Experiments

Greenhouse experiments were conducted using the selected lines from KMP1Fe grown in a composite of soil samples from fields known to produce chlorotic sorghum plants. The soil samples were a collection of Ulysses Silt Loam from the Garden City Branch Experiment Station, Garden City, Kansas. The soil was screened through a number 9 USA Standard Testing Sieve (2.36mm) and mixed with silica sand similar to Loeppert et al. (1984). The sand content in the soil was increased from 24 to 54 percent. Properties of this soil mixture are shown in Table 1. Nitrogen, phosphorous and zinc were added to insure adequate fertility and to avoid possible confounding nutrient deficiencies. The rates of application were as follows: 882 gm^{-3} NH_4NO_3, 258 gm^{-3} KH_2PO_4 and 114 gm^{-3} $ZnSO_4$. A portion of this soil was also ammended with FeEDDHA in the form of 219 gm^{-3} of Sequestrene 138 Fe (Ethylenediaminedi(O-hydroxyphenylacetate), 8.5% Fe as Fe_2O_3), obtained from Ciba-Geigy, to compare seedlings with and without added iron. The soil ammended with the FeEDDHA will be refered to as chelated. Each soil was mixed to insure homogeneity.

Height groups were studied in separate greenhouse experiments. A six replication split plot design was used in each of the three greenhouse experiments. The whole-plot consisted of the soil treatments and sub-plots of single plant entries from KMPlFe or check lines. Ks 5 served as an iron efficient check and Dwarf Redlan as an inefficient check. Checks were entered twice in each height group.

Seeds were germinated for 36 hours in incubation chambers set at 30°C. Three germinated seeds of a given entry were placed into a Super Cell Cone-Tainer greenhouse container filled with soil mixture. The containers measured 3.8 cm diameter at the top and tapered over 21 cm length to 2.5 cm diameter at the bottom and were purchased from Ray Leach Cone-Tainer Nursery in Canby, Oregon. Seeds were covered with 1 cm of vermiculite and then covered with a layer of perlite. Plants of abnormal vigor were thinned after emergence leaving one plant of similar vigor in each container.

Plants were rated visually on alternate days for chlorosis and vigor. The top two leaves of plants were scored for chlorosis from 0 to 5 using a system similar to Williams et al. (1982) and McKenzie et al. (1984). Plants receiving scores of 0 were non-chlorotic and those assigned scores of 5 were completely chlorotic with associated necrosis. Vigor scores were assigned relative to seedlings within a soil treatment using a scale of 0 to 4. Seedlings with the greatest vigor were assigned a 4, those plants with little vigor a 0 and plants with average vigor a 2. Seedlings in the short height group were evaluated on the 2nd

through the 26th alternate day after emergence. The medium and tall groups were evaluated on the 12th through the 20th alternate day after emergence. Final seedling height and dry weight were recorded one day after the last vigor and chlorosis rating. Dry weights were determined after drying shoots in a forced-air oven at 60°C for one week. Analysis of variance was performed on all height groups for chlorosis score, final height and shoot weight and vigor score (Table 2). Reps within treatments provided the error term, error a, for soil treatment effects. The rep by entries within treatment mean square was used to test for entry effects.

Field Experiment

A field experiment was planted June 8, 1984 at the Garden City Experiment Station, Garden Gity, Kansas to evaluate entries in a chlorosis-inducing field environment. The soil on which this experiment was conducted was a component of the soil mixture used in the greenhouse studies. Properties of this Ulysses Silt Loam are listed in Table 1. The experiment included the 18 best germinating lines from each of the height groups in the greenhouse studies. Ks 5, Plainsman and two-dwarf Plainsman served as efficient checks. Dwarf Redlan, Redlan and two-dwarf Redlan were each entered twice as inefficient checks. The 6 rep experiment was constructed in a blocks in replications (BIR) design (Schutz and Cockerham, 1962). Plots consisted of single rows 1.02 m wide by 4.5 m long. Plots were overplanted and thinned to approximately 65,550 plants per hectare.

Plots were evaluated for chlorosis 48 days after planting

using a rating system similar to that used in the greenhouse experiments. This system was expanded to include an additional class of chlorosis; a rating of 6 was given to plots with plants that had died as a result of chlorosis. Seventy-five days after planting, prior to grain fill, the foliage from 3m of competitive row length was harvested from each plot. Dry weights were determined by drying representitive samples from each plot in a forced-air oven at 60°C.

RESULTS

The effect of the soil treatment was significant in all greenhouse experiments for chlorosis, shoot length and dry weight (Table 2). Entry effects were significant in the short and tall groups for chlorosis and dry weight and also for shoot length in the tall group. Entry effects for vigor scores were significant in the short height group while entry effects were not significant in the medium or tall height group experiment. Similar results were noted for chlorosis score in an analysis of the non-chelated groups (Table 3).

Entry effects and entries within each height group were significant for chlorosis score and biomass in the field study (Table 4). Comparisons between the tall and the mean of the short and medium height groups were also significant for chlorosis score and biomass. The comparison between short and medium groups was significant for biomass but not chlorosis.

Means and ranks for greenhouse final chlorosis scores of entries grown in the non-chelated soil, along with field chlorosis score and field biomass are presented in Tables 5, 6 and 7 for the short, medium and tall height groups, respectively. The phenotypic correlation coefficient for field chlorosis score with field biomass was -0.91. Check lines in the field performed as expected in terms of their chlorosis scores, however, efficient checks were more chlorotic and produced less biomass than the best performing selections from the improved population, KMPFel. The range in chlorosis scores in non-chelated soil in the greenhouse experiments were 2.17 in the short and tall groups

and 1.67 in the medium group. Check lines generally performed the same in all greenhouse experiments. Chlorosis scores for efficient and inefficient checks in the greenhouse experiments were significantly different in the short group only.

Phenotypic correlation coefficients were computed to show the linear relationship between the chlorosis score of non-chelated greenhouse seedlings with field chlorosis score and biomass over time (Table 8). Correlations were not significant for any of the height groups until 14 days after emergence. Entries in the short height group were rated for the longest time period and showed the greatest linear association with field data. In all height groups there was a consistent pattern of greenhouse chlorosis scores being positively correlated with field chlorosis scores and negatively correlated with biomass. The magnitude and significance of these relationships increased over time. These relationships were also seen in the medium height group despite there being no significant entry mean square for chlorosis score.

Final greenhouse scores were significantly correlated with field chlorosis and biomass in all height classes (Table 9). Correlations involving seedling dry weight with field biomass and chlorosis score were significant for the short height group. All other correlations involving shoot length, seedling dry weight and vigor score with field data were non-significant. Multiple linear regression was used to describe field chlorosis and biomass in the short group with entries grown in the greenhouse in the non-chelated soil mixture. The following model was

constucted:

$$\text{Field} = 2.591 + 0.617\, C + -0.083\, L + -0.527 W + 1.786\, V$$

where Field equals predicted field chlorosis score, C equals greenhouse final chlorosis score, L equals final shoot length, W equals final dry weight and V equals final vigor score. The coefficient of determination (R^2) for this model was 0.77. The R^2 for the model constucted to explain field biomass with the same variables was 0.62. A quadratic polynomial model using final greenhouse chlorosis scores of the short group to describe field biomass and chlorosis score yielded R^2 values of 0.67 and 0.78 (Figure II-1), respectively. Similar models used to explain field chlorosis score with final greenhouse score for the medium and tall groups are presented in figures II-2 and II-3, respectively.

DISCUSSION

The time and cost benefits of visually screening greenhouse grown seedlings to predict field iron deficiency chlorosis performance could be substantial. Research correlating total iron content (Pierson et al., 1984) and leaf chlorophyll content (Cianzio et al., 1979; McKenzie et al., 1984) with visual scores has established the usefulness of visual evaluation for chlorosis. McKenzie et al. (1984) evaluated seedlings of 9 sorghum lines known to vary in iron efficiency grown in $CaCO_3$ buffered nutrient solutions and scores agreed with known field performance. Loeppert et al. (1984) have demonstrated a linear relationship of visual evaluations of Redlan seedlings grown in 31 "hot spot" soils with Redlan seedlings grown in the same soils in the greenhouse. Work by Kannan (1982) has pointed out potential problems in assuming that the behavior of seedlings agrees with adult sorghum plants. His investigations have shown adventitious roots of iron efficient sorghum plants to be more effective than seminal roots in decreasing the pH of the medium in which plants are grown. Nevertheless, good correlation of greenhouse cultivated seedlings with mature field plants has been demonstrated in soybeans by Coulombe et al. (1984) and in oats (*Avena byzantina* (C.) Koch) by McDaniel and Brown (1982).

The strong correlation of greenhouse chlorosis score with field chlorosis score and biomass in this study supports using sorghum seedlings to predict the chlorosis reaction of more mature plants. Regression models using seedling chlorosis to predict mature plant chlorosis score and biomass agrees with

these findings and further support the usefulness of greenhouse screening. Including seedling dry weight, final length and vigor score in the models did not provide a better explanation of field chlorosis and biomass than greenhouse chlorosis scores alone.

The effect of the FeEDDHA treatment was significant for final chlorosis score, shoot length and shoot dry weight for all height groups in the greenhouse experiments. The height group means for these variables in the two soil treatments confirm that chlorosis resulted from a deficiency of iron and that the addition of this nutrient significantly improved plant height and weight (Table 10).

The performance of entries within height groups varied in the greenhouse experiments. This was evidenced by the significant mean squares for final seedling chlorosis and dry weight in the short and tall height groups and for shoot length in the tall group. Significant soil treatment by entry interactions indicate entries did not have the same relative performance in the two soil treatments. Anderson and Parkpian (1984) and Romheld and Marschner (1984) have shown that inefficient lines are more responsive to added iron than efficient lines and this could explain the significant treatment by entry interactions. Check lines generally had the same relative performance in all experiments. Results presented in tables 4, 5 and 6 show the efficient checks to be intermediate to selections from the KMPlFe with respect to greenhouse chlorosis, field chlorosis and biomass.

No statistical comparisons can be made among the three

height groups in the greenhouse experiments, although several criteria suggest that the short group experiment was the most sensitive of the three. These criteria include: the low error mean square for chlorosis, the greater mean chlorosis score, the significant difference between Dwarf Redlan and Ks 5, the large range in final chlorosis rating, the significant correlation of seedling dry weight with field biomass chlorosis score and the strong correlation of field and greenhouse chlorosis scores. The greater sensitivity may be attributable to its duration test. The importance of duration is indicated with the increase of correlation coefficients over time for field chlorosis and biomass with greenhouse chlorosis scores. Comparing correlation coefficients over time of the short and medium groups for greenhouse chlorosis scores with field data show differences despite the means of these groups not being statistically different in field chlorosis. Although the F ratio for entries was not significant for final greenhouse chlorosis score in the medium group a significant correlation existed between greenhouse chlorosis and field results. The tall, more efficient class showed less of a relationship with field data than the medium group in studies of equal duration. These comparisons suggest that the results could be related to factors other than duration, such as the efficiency of the lines being screened or environmental factors confounded with the date of experimentation.

Greenhouse chlorosis scores were significantly correlated with field chlorosis and biomass in all height groups. This supports the use of greenhouse chlorosis data to predict field

results. Lines could be screened in the greenhouse and the most chlorotic lines excluded from further evaluations. Regression analysis indicated that including other seedling traits did not increase the predictive value of greenhouse screening. Certainly, caution must be exercised in extrapolating these results to apply to all soils known to cause iron deficiency chlorosis. Iron deficiency chlorosis is affected by many factors (Walace, 1982) which in turn can cause the relative iron efficiency of a given genotype to vary with location as noted in both lovegrass (Voight et al., 1982) and sorghum (Loeppert et al., 1984). As previously suggested, the sensitivity of this technique may be related to the efficiency of the lines being screened and/or environmental factors. Although this screening method may be refined, either by considering specific environmental factors or improvement of experimental techniques, results indicate the field chlorosis performance of a large number of sorghum genotypes can be predicted by evaluating seedling chlorosis in a non-field environment.

Table II-1. Properties of soils mixed with sand for greenhouse experiments prior to addition of chemical ammendments and a Ulysses Silt Loam soil used in the field experiment at Garden City, KS.

	Greenhouse	Field
pH	8.1	8.1
Organic matter (%)	1.1	1.3
Sand (%)	54.0	25.5
Silt (%)	30.0	48.0
Clay (%)	16.0	26.5
Iron (ppm)*	3.0	4.5
Zinc (ppm)*	0.7	0.3
Calcium (ppm)	2320	4903

* Levels of iron and zinc were increased by ammendment to 63.0 ppm and 12.6 ppm, respectively.

Table II-2. Mean squares from greenhouse experiments on short, medium and tall classes of random lines from KMP1Fe sorghum population and check lines.

Source	df	Mean Square Visual chlorosis score	Shoot length	Shoot Weight	Vigor score
<u>Short</u>					
Soil treatment	1	544.05**	735 006**	9 091 750**	99.3
Error a	10	1.11	10 529	13 760	36.7
Entry	25	1.38**	3616	65770**	101.2**
Entry x Soil	25	1.01**	2 556	42 940	81.8
Error b	250	0.39	2 749	35 180	54.3
<u>Medium</u>					
Soil treatment	1	240.66**	807 945**	2 059 690**	177.0**
Error a	10	0.97	8 810	35 010	30.0
Entry	25	0.60	3 080	14 190	39.7
Entry x Soil	25	0.60	8 358*	35 205**	96.4**
Error b	250	0.51	5 053	16 507	44.8
<u>Tall</u>					
Soil treatment	1	126.95**	399 470**	1 813 990**	9.7
Error a	10	0.77	10 108	26 390	25.7
Entry	25	1.17**	6 739**	38 990**	65.1
Entry x Soil	25	0.98**	4 394*	29 101	58.7
Error b	250	0.36	3 400	21 002	42.3

*,** Significant at $p \leq 0.05$ and 0.01, respectively.

Table II-3. Mean squares from greenhouse experiments on short, medium and tall classes of random lines from KMPlFe sorghum population and check lines grown in a chlorosis inducing soil mixture.

		Mean Square			
Source	df	Visual chlorosis score	Shoot length	Shoot Weight	Vigor
Short					
Entry	25	2.33**	3383.6	31 818	0.92*
Rep	5	2.19	1882.9	3 561	0.54
Error	125	0.78	2693.5	23 817	0.56
Medium					
Entry	25	1.18	4984.1	15 780	0.71
Rep	5	0.19	6332.1	78 900	0.35
Error	125	1.01	5440.1	11 302	0.48
Tall					
Entry	25	2.15**	5294.5	27 883	0.57
Rep	5	1.5	3863.3	3 411	0.08
Error	125	0.70	3946.4	18 270	0.43

*,** Significant at $p \leq 0.05$ and 0.01, respectively.

Table II-4. Analysis of variance of field visual chlorosis score and biomass for random lines from KMPlFe sorghum population grouped into classes of similar heights and check lines in 1984 at Garden City KS.

Source	df	Biomass yield	Chlorosis score
Rep	5	121 096**	7.06*
Entry	62	57 419**	3.72**
Among height classes	2	144 072**	15.88**
Tall vs 1/2(short + medium)	1	263 076**	31.37**
Short vs medium	1	25 076**	0.39
Within Height classes	60	54 531**	3.39**
Short	20	55 389**	2.79**
Medium	20	51 332**	2.39**
Tall	20	56 871**	4.77**
Error	310	4 594.56	0.206

** Significant at 0.01 level of probability.

Table II-5. Means and ranks of short height entries final chlorosis score evaluated in the greenhouse using a chlorosis inducing soil and of field chlorosis score and biomass evaluated at Garden City, KS in 1984.

	Greenhouse		Field			
Entry	Chlorosis Score	Rank	Chlorosis Score	Rank	Biomass	Rank
	(0-5)		(0-6)		gm^{-2}	
KMPlFe-136	2.33	7	2.07	1	384.7	1
KMPlFe-37	2.66	9	2.07	1	351.0	3
KMPlFe-65	2.00	3	2.15	3	305.6	4
KMPlFe-209	2.08	5	2.15	3	293.3	6
KMPlFe-222	1.83	1	2.40	5	379.1	2
KMPlFe-133	1.83	1	2.48	6	294.7	5
KMPlFe-168	2.33	7	2.57	7	287.9	7
KMPlFe-254	2.00	3	2.65	8	269.4	9
KMPlFe-154	2.25	6	2.73	9	223.9	12
KMPlFe-160	2.66	9	2.73	9	211.3	14
KMPlFe-19	3.00	11	2.73	9	233.7	15
KMPlFe-173	3.16	14	2.82	12	278.0	8
KMPlFe-162	3.16	14	2.82	12	240.0	11
KMPlFe-174	3.16	14	2.82	12	221.3	13
KMPlFe-13	3.00	11	3.07	15	249.2	10
KMPlFe-135	3.00	11	3.07	15	175.7	16
KMPlFe-172	3.33	18	3.15	17	168.4	17
KMPlFe-27	3.16	14	3.65	18	104.3	18
Checks						
KS5	3.16		2.48		245.2	
Dwarf Redlan-1	4.00		4.40		45.9	
Dwarf Redlan-2	3.83		4.65		15.2	
LSD(0.05)	0.714		0.514		76.70	

Table II-6. Mean and rank of medium height entries field chlorosis score evaluated in the greenhouse using a chlorosis inducing soil and of field chlorosis score and biomass evaluated at Garden City, KS in 1984.

	Greenhouse		Field			
Entry	Chlorosis Score	Rank	Chlorosis Score	Rank	Biomass	Rank
	(0-5)		(0-6)		gm^{-2}	
KMPlFe-152	1.50	9	2.07	1	357.9	1
KMPlFe-126	1.41	6	2.15	2	338.3	3
KMPlFe-75	1.41	6	2.23	3	341.3	2
KMPlFe-77	1.00	1	2.32	4	268.8	7
KMPlFe-73	1.33	3	2.32	4	298.2	4
KMPlFe-125	1.33	3	2.48	6	239.5	10
KMPlFe-83	1.75	10	2.57	7	261.4	8
KMPlFe-278	2.00	14	2.57	7	277.1	6
KMPlFe-155	1.25	2	2.73	9	258.3	9
KMPlFe-204	1.33	3	2.82	10	295.5	5
KMPlFe-206	1.41	6	2.82	10	207.1	11
KMPlFe-25	2.16	17	2.82	10	204.7	12
KMPlFe-41	2.00	14	3.07	13	183.8	13
KMPlFe-192	1.75	10	3.15	14	159.3	14
KMPlFe-79	2.33	18	3.15	14	132.5	17
KMPlFe-270	1.75	10	3.32	16	150.2	16
KMPlFe-66	2.08	16	3.65	17	101.0	18
KMPlFe-141	1.91	13	3.73	18	151.4	15
<u>Checks</u>						
Plainsman	-		2.90		251.8	
Redlan-1	-		4.32		57.7	
Redlan-2	-		4.14		28.3	
Ks 5	2.33		2.48		245.2	
Dwarf Redlan-1	2.34		4.40		45.9	
Dwarf Redlan-2	2.67		4.65		15.2	
LSD(0.05)	0.804+		0.514		76.70	

+ Values in column did not prove to be significantly different at the 0.05 level in an F test.

Table II-7. Means and ranks of tall height entries final chlorosis score evaluated in the greenhouse using a chlorosis inducing soil and of field chlorosis score and biomass evaluated at Garden City, KS in 1984.

	Greenhouse		Field			
Entry	Chlorosis Score	Rank	Chlorosis Score	Rank	Biomass	Rank
	(0-5)		(0-6)		gm^{-2}	
KMPlFe-107	0.50	2	1.15	1	395.2	2
KMPlFe-3	0.33	1	1.32	2	330.0	8
KMPlFe-92	0.75	3	1.42	3	348.3	6
KMPlFe-150	0.83	5	1.48	4	272.9	13
KMPlFe-243	1.25	12	1.57	5	320.1	9
KMPlFe-176	0.75	3	1.73	6	270.0	16
KMPlFe-219	1.08	6	1.73	6	408.5	1
KMPlFe-50	1.16	7	1.73	6	378.1	4
KMPlFe-62	1.91	18	1.73	6	354.5	5
KMPlFe-63	1.50	11	1.82	10	395.3	3
KMPlFe-157	1.16	7	1.90	11	294.3	10
KMPlFe-142	1.42	14	2.23	12	340.7	7
KMPlFe-101	1.16	7	2.48	13	276.2	11
KMPlFe-166	1.50	16	2.57	14	259.0	18
KMPlFe-198	1.16	7	2.82	15	271.6	14
KMPlFe-179	1.25	12	2.73	16	270.3	15
KMPlFe-69	1.42	14	2.73	16	252.0	17
KMPlFe-26	1.83	17	2.90	18	274.1	12
<u>Checks</u>						
Plainsman	-		2.90		188.9	
Redlan-1+	-		4.32		53.2	
Redlan-2+	-		4.40		26.0	
Ks 5	2.42		2.48		245.2	
Dwarf Redlan-1	1.67		4.40		45.9	
Dwarf Redlan-2	2.50		4.65		15.2	
LSD(0.05)	0.674		0.514		76.70	

+ Two dwarf.

Table II-8. Correlation coeficients over time for chlorosis scores in greenhouse studies of three height groups in a chlorosis inducing soil with field visual chlorosis score and biomass yield.

	Field					
	Short		Medium		Tall	
Days post emergence	Score	Biomass	Score	Biomass	Score	Biomass
2	0.00	0.00	-	-	-	-
4	0.00	0.00	-	-	-	-
6	0.19	-0.15	-	-	-	-
8	0.43	-0.33	-	-	-	-
10	0.27	-0.11	-	-	-	-
12	0.30	-0.27	0.27	-0.23	0.00	0.00
14	0.44*	-0.47*	0.25	-0.19	0.33	-0.08
16	0.47*	-0.47*	0.64**	-0.54*	0.61*	-0.40
18	0.62*	-0.61**	0.71**	-0.64**	0.65**	-0.46*
20	0.67**	-0.64**	0.75**	-0.77**	0.68**	-0.52*
22	0.72**	-0.63**	-	-	-	-
24	0.72**	-0.68**	-	-	-	-
26	0.78**	-0.78**	-	-	-	-

*, ** significantly different than zero at $p \leq 0.05$ and 0.01, respectively.

Table II-9. Phenotypic correlation coefficients for final visual chlorosis score, final vigor score, final shoot length and dry weight of entries from three height groups grown in chlorosis inducing soils in the the greenhouse with field visual chlorosis scores and biomass.

	Field					
	Short		Medium		Tall	
Greenhouse	Score	Biomass	Score	Biomass	Score	Biomass
Chlorosis score	0.78**	-0.78**	0.75**	-0.77**	0.68**	-0.52*
Vigor score	0.06	0.06	0.05	0.09	0.13	-0.17
Shoot length	-0.19	0.27	-0.06	0.19	0.16	-0.28
Shoot dry weight	-0.51*	0.49*	-0.11	0.21	-0.02	-0.01

*, ** significantly different than zero at $p \leq 0.05$ and 0.01, respectively.

Table II-10. Mean final visual chlorosis score, shoot length and dry weight for greenhouse experiments on short, medium and tall height classes of KMP1Fe sorghum population grown in FeEDDHA treated soil and soil without FeEDDHA.

Height class	+Soil treatment		Chlorosis score	Shoot length	Dry weight
				mm	mg
Short	None		2.68	364	421
	FeEDDHA		0.04	461	763
		LSD	0.265	2.6	29.5
Medium	None		1.77	366	311
	FeEDDHA		0.01	468	473
		LSD	0.247	2.4	47.2
Tall	None		1.29	427	395
	FeEDDHA		0.01	498	547
		LSD	0.222	2.5	41.4

+ All soils ammended with N, P, K, S, and Zn.

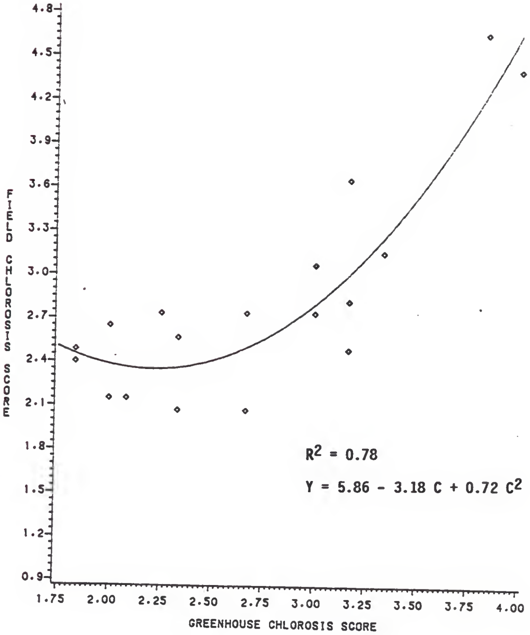

Figure II-1. The relationship of short height group final greenhouse chlorosis scores with field chlorosis score.

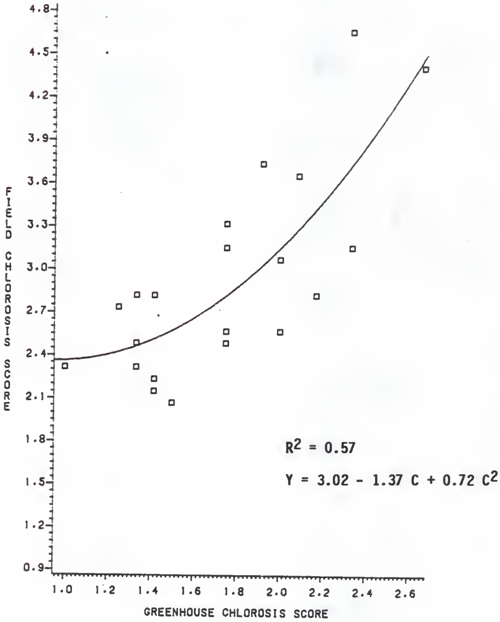

Figure II-2. The relationship of medium height group final greenhouse chlorosis scores with field chlorosis scores.

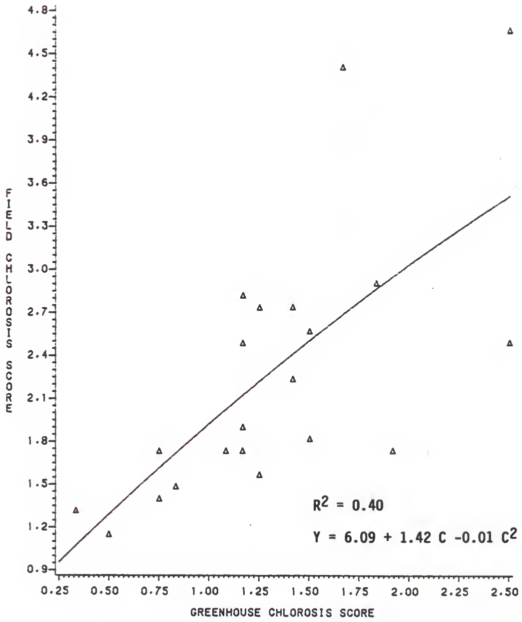

Figure II-3. The relationship of tall height group final greenhouse chlorosis scores with field chlorosis scores.

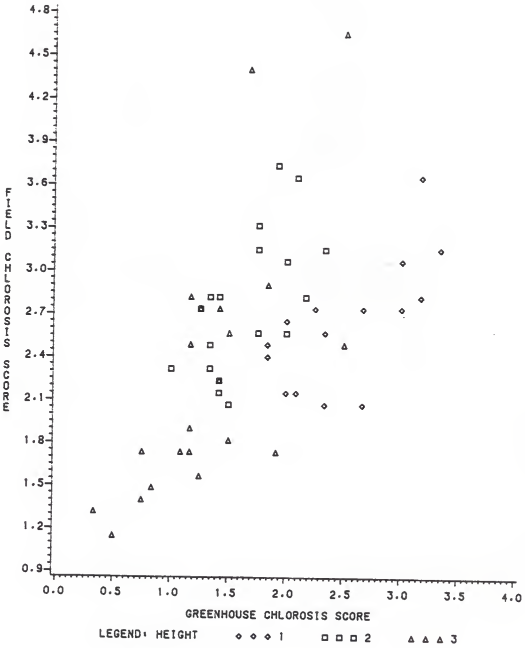

Figure II-4. The relationship of final greenhouse chlorosis scores with field chlorosis scores.

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IRON DEFICIENCY CHLOROSIS IN SORGHUM

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The purpose of these investigations was to evaluate the effect of iron deficiency chlorosis on biomass, to investigate the inheritance of iron efficiency and to evaluate a greenhouse screening technique for predicting field iron deficiency chlorosis in sorghum (Sorghum bicolor (L.) Moench). Random lines from KMPlFe, a population having undergone recurrent phenotypic selection for iron efficiency were classified into three groups of short (75-118 cm), medium (119-141 cm) and tall (142-175 cm) entries. Single row plots were visually evaluated for chlorosis 46 days after planting in 1983 and 32 and 48 days after planting in 1984. Chlorosis scores for the two years were significantly correlated (r=0.82). Above ground biomass, measured from one meter of competitive row length was harvested 75 days after planting, prior to grain fill in 1984. Chlorosis scores in 1983, the mean of 1984 scores and the mean of both years were all negatively correlated with biomass. Regression analysis indicated that chlorosis had a major effect on biomass.

Parents and progeny of a factoral mating design involving four females and twenty-five males were planted in a four rep BIR design at the same site in 1984. Plots were evaluated for chlorosis 48 and 74 days after planting. The inheritance of chlorosis score was largely additive; general combining ability accounted for 80% of the genetic variance among hybrids and the level of heterosis was only 5%. Male line performance per se and inter se were significantly correlated as were male lines per se,inter se and male lines with specific females.

Seedlings were grown in a soil mixture high in pH and calcium carbonate, and low in organic matter and available iron. Three six rep split plot experiments were conducted in the greenhouse with FeDDEHA amended soil as a control treatment. Seedlings of the selected lines from KMP1Fe were evaluated for chlorosis, vigor, shoot length and dry weight. Mean squares for chlorosis and dry weight were significant for the short and tall groups but not for the medium. Greenhouse results were compared to those of field experiment conducted on a site known to induce severe chlorosis symptoms in sorghum. Single row plots were visually evaluated for chlorosis 48 days after planting and biomass was determined for one meter lengths of competitive row 75 days after planting. Phenotypic correlations between greenhouse chlorosis scores for all non-chelated entries with field chlorosis scores and biomass were significant. Regression analysis on the short non-chelated group using greenhouse chlorosis scores to describe field chlorosis and biomass provided R^2 values of 0.78 and 0.67, respectively. Results indicated that greenhouse chlorosis score from the soil based seedling method could be used to predict field performance.